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OPTIMIZING TIMING FOR EMERGENCY VEHICLE APPROACHING WARNINGS

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Abstract. Emergency driving is a demanding task. The ITS service *Emergency Vehicle Approaching* provides drivers with an in-car warning that an emergency vehicle is approaching. To ensure that the warning is efficient and reliable it must have a suitable timing. The EVA warning must be presented early enough to allow the driver to make a safe move-over maneuver. However, the distribution of EVA warnings is based on the most probable path of the emergency vehicle. If an EVA warning is distributed too early, it increases the risk of false alarms. In addition, if a warning is given too early the driver might deem it as irrelevant.

Previous studies have distributed EVA warnings based on the distance between the emergency vehicle and surrounding cars. However, if the speed of the vehicle is not accounted for there is a risk of insufficient time for the driver to prepare for the emergency vehicle interaction. To explore suitable EVA timing, post-survey data from five driving simulator studies where drivers were exposed to EVA warnings were analyzed. The results suggest that 15–20 seconds could be an appropriate EVA timing. However, the required time for a move-over maneuver depends on the complexity of the current traffic situation.

Keywords: Emergency vehicle, intelligent transport systems, Emergency Vehicle Approaching, warning.

1. Introduction

The interaction between emergency vehicle operators and civilian drivers can result in accidents [1]. Driving an emergency vehicle often entails high-risk factors such as speeding, multitasking, and interacting with other road users [2]. Civilian drivers who encounter an emergency vehicle in traffic can find the situation stressful. Due to the soundproofness of new cars and the limitations of emergency lights and sirens, the civilian driver might not have enough time to move over for the approaching emergency vehicle. One way to mitigate the risks associated with emergency vehicle-related accidents is to provide surrounding vehicles with an Emergency Vehicle Approaching (EVA)-warning [3]. An EVA warning is an in-car warning letting the driver know that they soon must prepare for an oncoming emergency vehicle.

Several previous studies have examined the effects of EVA warnings on drivers' behavior. However, no study has examined what the optimal timing of an EVA warning would be. Instead, different occasions to distribute the warning, either time or distance-based have been described in previous research. In Lenné et al. [4], the civilian driver would receive the warning when they were inside a 300–400 meters radius of the emergency vehicle. In Savolainen [5], drivers were notified when the emergency vehicle was 2 000 feet (approx. 610 m) from an intersection that the civilian driver was heading towards. In Lidestam et al. [6], EVA timings of both 14 and 50 seconds were used. In Payre and Diels [7], the drivers received the EVA warning 30 seconds before the emergency vehicle overtook them.

A warning should be given at such a time that the driver has time to prepare for the oncoming situation. However, presenting it too early could also have consequences. Firstly, if a warning is presented but too long time passes without a sign of danger, they are probably going to believe that the warning was false and therefore disregard it. Secondly, if a warning is presented too early there is a risk that the prognosis the warning was based on will change. For instance, the emergency vehicle decided on a new route. Thereby, no longer affecting the drivers who received the warning. It is therefore important to find a timing of EVA warning that provides the driver with enough time to move over, but at the same time find a timing that minimizes the risk of either real or perceived false alarms. In the present paper, the optimal time for EVA warnings is examined by analyzing survey data from five different driver simulator studies.

2. Method

Short descriptions of the driving simulator studies included are presented below.

2.1. Study 1 – Highway experiment

This study included 110 drivers aged 18–61 years, $M = 38.2$, $SD = 15.2$ years. The participants were driving on a highway for 30 minutes and received EVA warnings three times (11,19 and 27 minutes into the simulation). The drivers received a randomized combination of false and true alarms. In the events with true EVA warnings, the drivers were approached by an emergency vehicle 15 seconds after receiving the alert. Only participants who received true EVA warnings ($n = 32$) are included in the current study.

2.2. Study 2 – Highway experiment with eye tracking

In the eye-tracking experiment, the same scenario was used as in the highway experiment, but with the warning presented 20 seconds before the emergency vehicle overtook the participant's vehicle. Two interactions with the emergency vehicle occurred, 9 and 15 minutes into the scenario. In Study 2, 73 drivers participated with an age range of 19–54 years ($M = 38.1$, $SD = 10.1$). Only participants from the experimental group ($n = 35$) are included in the current study, as the control group did not receive any in-car warnings.

2.3. Study 3 – Offramp

The study included 30 drivers, aged 19–82 years, $M = 51.5$, $SD = 14.6$. In the scenario, the drivers were instructed to follow the signs on a highway to the Swedish city of Trosa. However, when approaching the offramp that would take them to Trosa, half of the participants received an in-car warning that there had been an accident on the offramp and that they therefore should continue straight ahead. The warning was presented 15 seconds before they would have entered the offramp. Only participants from the experimental group ($n = 15$) are included in the current study, as the control group did not receive any in-car warnings.

2.4. Study 4 – Crossing scenario

In this study, 34 drivers, aged 19–78 years, $M = 49.7$, $SD = 17.4$ were included. In the scenario, they were driving in a city environment. After a few minutes, the participant would approach an intersection. Half of the participants would receive an in-car warning instructing them to stop before the intersection due to an approaching emergency vehicle. The warning was presented 12 seconds before the driver entered the intersection. Only participants from the experimental group ($n = 17$) are included in the current study, as the control group did not receive any in-car warnings.

2.5. Study 5 – Augmented Emergency Lighting

Study 5 was a replication of Lidestam et al. [6] but with experienced instead of inexperienced drivers. In addition, half of the participants were given an ambient in-car light 15 seconds before the EVA warning was given. After the EVA warning was presented, it took 14 seconds before the emergency vehicle would overtake the participant's vehicle. In the study, 62 drivers participated, with an age range of 29–80 years ($M = 58.3$, $SD = 12.9$). However, in the present paper, only the drivers who received an EVA warning and no ambient light or control group are included ($n = 20$).

3. Results

In studies 1-4 the participants were asked the same questions about their experience of the in-car warnings in the post-survey. All answers were indicated on a 1–7-degree Likert scale (1 = Fully disagree, 7 = Fully agree). For the purpose of this study, the participants were grouped depending on the warning timing of the study they participated in. The participants in Study 4 were placed in group *12 sec*. The participants from Studies 1 and 3 formed group *15 sec*, and participants from Study 2 were put in group *20 sec*. The potential difference between the groups was examined through between groups ANOVAs followed by a Tukey HSD post hoc analysis. The descriptive result of the questionnaire is presented in Figure 1.

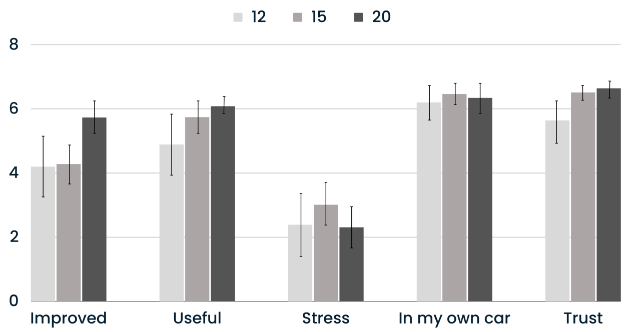

Figure 1. Post survey questions regarding experience of the EVA warning system for 12,15 and 20 sec warning timing (Likert scale on y-axis, 1 = Strongly disagree, 7 = Strongly agree).

The participants were asked to what extent they agreed with the statement *"The warning improved my driving behavior"*. The result indicated a significant difference between the groups, $F(2, 80) = 7.59$, $p < .001$, $\eta_p^2 = .16$. The Tukey HSD post hoc analysis indicated that drivers who received the EVA warning 20 sec before interacting with the emergency vehicle to a larger extent believed that the warning improved their driving compared to the drivers who received the warning 12 ($p = .01$) or 15 sec ($p = .002$) before the emergency vehicle interaction.

When asked to what extent *"The warning was useful"*, the ANOVA test suggested a significant difference between the groups $F(2, 80) = 3.30$, $p = 0.042$, $\eta_p^2 = .08$. The post hoc analysis suggested that the 20 sec group agreed with the statement to a larger extent compared to the 12 sec group ($p = .033$). There was no significant difference when comparing the 15 sec group with the 12 ($p = .145$) and 20 sec ($p = .634$) groups.

There were no indications of significant difference between the groups in terms of how much stress they experienced when receiving the warnings ("*The warning made me stressed"*), $F(2, 80) = 1.42$, $p = .25$.

When asked to indicate to what degree the agreed with the statement *"I would like to receive these warning in my own car in the future"*, the ANOVA did not indicate a significant difference between the groups, $F(2, 80) = 0.48$, $p = .62$.

Finally, the participants were asked to what degree they believed *"I felt that I could trust the warning"*. The ANOVA suggested a significant difference between the groups, $F(2, 80) = 8.08$, $p < .001$, $\eta_p^2 = .17$. The post hoc analysis indicated that the 12 sec group experienced a lower degree of trust compared to the 15 ($p = .002$) and 20 sec ($p < .001$) groups. However, there was no significant difference between the 15 and 20 sec groups ($p = .835$).

In study 5, the participants were asked about the timing of the EVA warning (Figure 2). A majority of participants (60 %) believed that the warning had sufficient timing. About a third of participants (35 %) would have liked the warning to come earlier, and five percent would have liked a later warning.

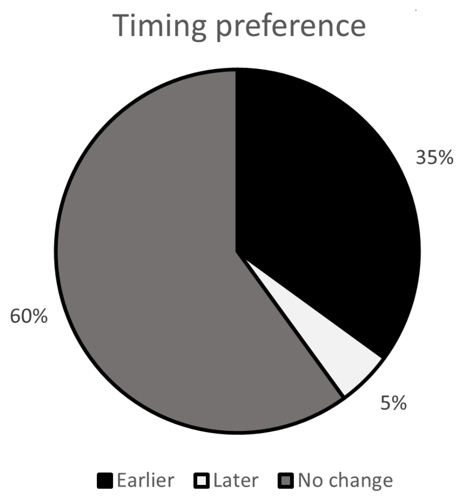

FIGURE 2. Evaluation of timing suitability (Study 5).

4. DISCUSSION

The results of the questionnaires from Study 1-4 indicate that drivers are positive towards EVA warnings. Independent of the warning timing, the drivers indicated that they would like to have EVA warnings in their own vehicles. The indicated level of stress when faced with the warnings was relatively low. However, in some respects, the participants seem to prefer a longer EVA timing. This preference was indicated for how much the EVA warning improved the participants' driving behavior and the level of trust associated with the EVA warning. Furthermore, drivers in the *20 sec* group found the EVA warning significantly more useful compared to the *12 sec* group.

The results regarding timing from Study 5 suggested that most participants were satisfied with an EVA warning presented 14 seconds before the emergency vehicle interaction. However, a third of participants believed that the warning should have been presented earlier. This further supports that a suitable timing of an EVA warning could be around 15–20 seconds.

The results of the present study suggest that the timing of EVA warnings is important. Previous studies examining the effectiveness of EVA have used a distance-based warning trigger [3, 5]. The distance trigger in Lenné et al. [3] would for instance result in 36–48 seconds to plan and perform a safe move-over maneuver when driving 30 kph and only 9–12 seconds when driving 120 kph. To ensure an EVA warning that is distributed in time, speed is a factor that must be considered.

One limitation of the present paper is the differences between the simulation scenarios used in the different studies. However, the results could still give a first indication of what a suitable EVA warning timing could be. The interaction between emergency vehicle operators and civilian drivers is risky, but an EVA warning with sufficient timing could mitigate the accident risk.

5. CONCLUSION

EVA warning can support drivers in interactions with emergency vehicles. Drivers are positive about the idea of having EVA warnings in their own vehicles. However, the timing of the EVA warning could affect the perceived benefit of the system. EVA warnings should be distributed with regards to the time it will take for the emergency vehicle to reach the civilian vehicle, rather than based on the distance between the emergency and civilian vehicle.

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